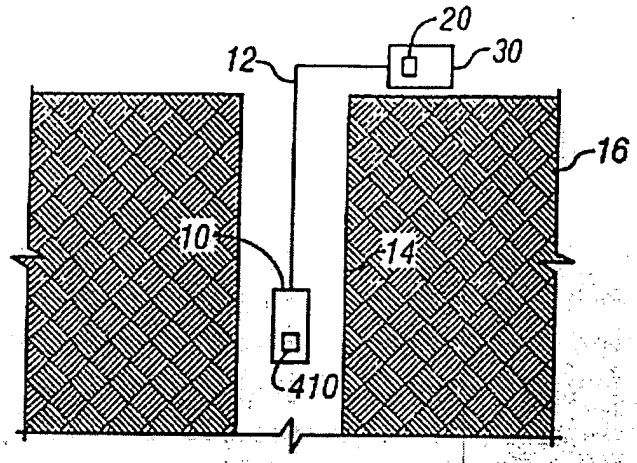


FIG. 1

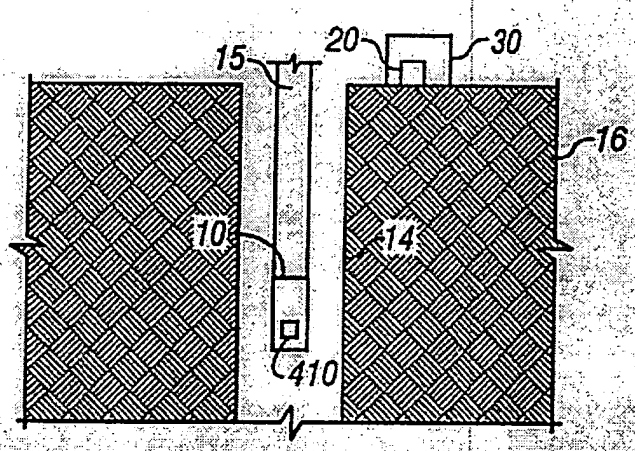


FIG. 2

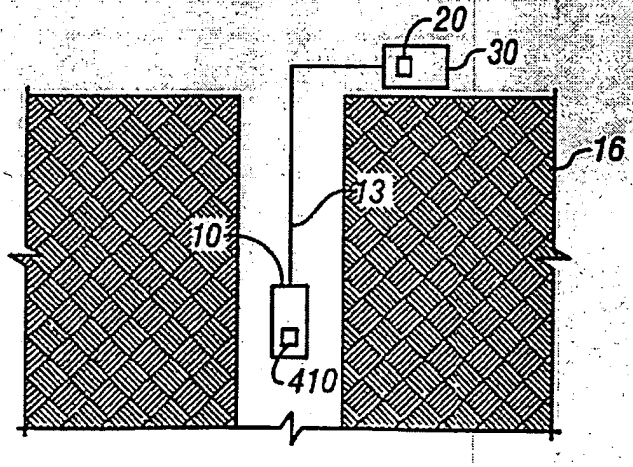


FIG. 3

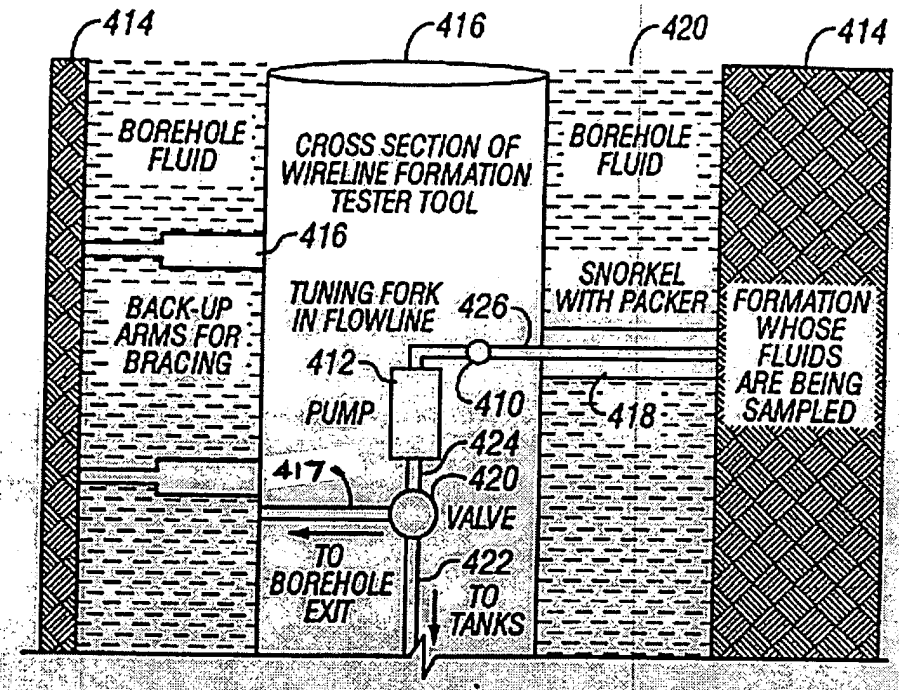


FIG. 4

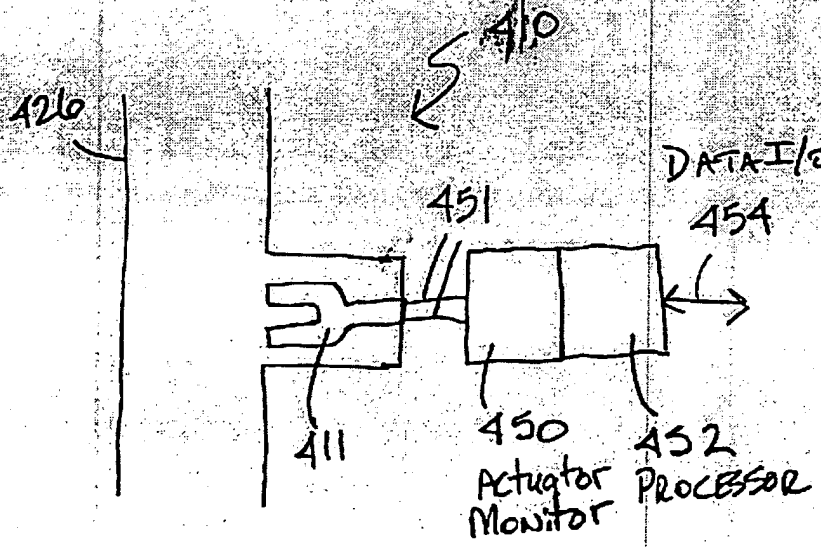


FIG. 5

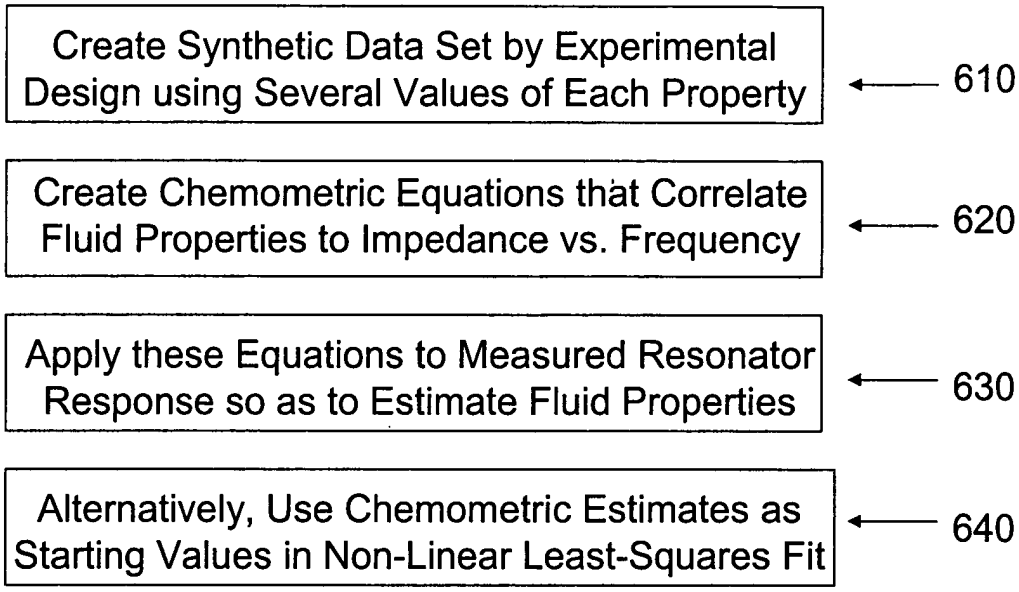

Create Synthetic Data Set by Experimental Design using Several Values of Each Property
610
Create Chemometric Equations that Correlate Fluid Properties to Impedance vs. Frequency
620
Apply these Equations to Measured Resonator Response so as to Estimate Fluid Properties
630
Alternatively, Use Chemometric Estimates as Starting Values in Non-Linear Least-Squares Fit
640

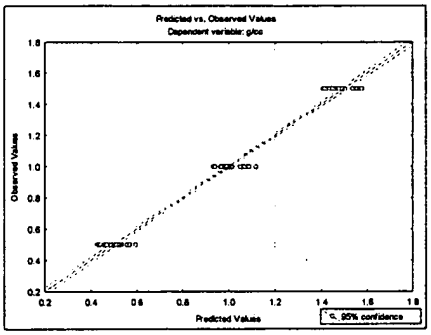
Figure 6

Fig. 7

Density

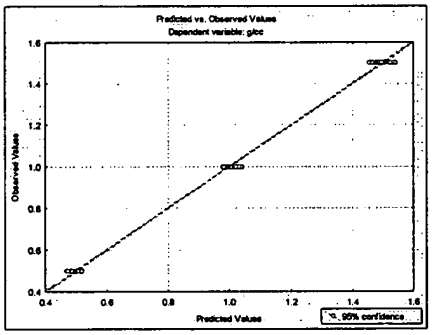
Regression Summary for Dependent Variable: g/cc (Synthetic Impedance Data.sta)
R= .99283581 R²= .98532585 Adjusted R²= .98514010
F(1,79)=5304.6 p<0.0000 Std.Error of estimate: .05053

	Beta	Std.Err.	B	Std.Err.	t(79)	p-level
Intercept			-10.0370	0.151558	-66.2254	0.00E+00
1/FLZD1	0.992838	0.013629	32.4538	0.445593	72.8328	0.00E+00



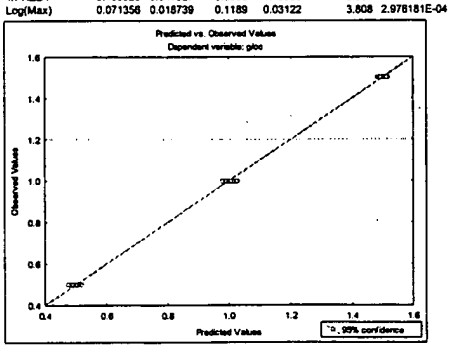
Regression Summary for Dependent Variable: g/cc (Synthetic Impedance Data.sta)
R= .99909311 R²= .99818705 Adjusted R²= .99801321
F(7,73)=5741.8 p<0.0000 Std.Error of estimate: .01848

	Beta	Std.Err.	B	Std.Err.	t(73)	p-level
Intercept			-9.8709	0.08397	-117.550	0.00E+00
log(MaxD2)	0.158008	0.014018	0.0563	0.00500	11.272	1.21E-17
1/FMin_D1	0.714452	0.090942	23.2643	2.96131	7.856	2.62E-11
Cub_Min	0.729493	0.114662	100.5412	15.82487	6.353	1.61E-08
Cub_Avg	-0.738300	0.119953	-98.6059	16.02087	-6.155	3.67E-08
MinD2	0.046837	0.012946	348.1813	95.88643	3.618	5.44E-04
1/FLZD1	0.323058	0.090546	10.5622	2.96037	3.568	6.40E-04
Sqr_Min	0.106548	0.042182	3.0742	1.21708	2.526	1.37E-02



Regression Summary for Dependent Variable: g/cc (Synthetic Impedance Data.sta)
R= .99970856 R²= .99941721 Adjusted R²= .99933396
F(10,70)=12004. p<0.0000 Std.Error of estimate: .01070

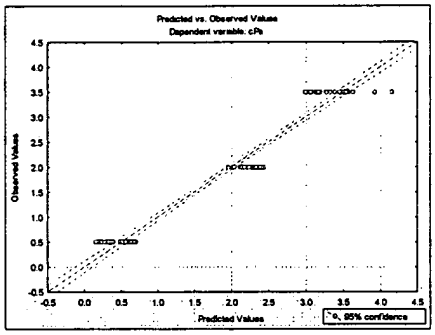
	Beta	Std.Err.	B	Std.Err.	t(70)	p-level
Intercept			-10.1349	0.04869	-208.130	0.000000E+00
log(MaxD2)	0.086594	0.006457	0.0309	0.00230	13.426	4.607740E-21
1/MinD2	0.117544	0.009139	0.0000	0.00000	12.862	4.117729E-20
1/MaxD1	0.052427	0.006022	0.0000	0.00000	8.706	9.173387E-13
AvgD1	-0.047915	0.006490	-93.3906	12.64923	-7.383	2.489016E-10
1/FMin_D2	0.447306	0.082745	13.8455	2.56121	5.406	8.448959E-07
1/FMin_D1	0.446249	0.086245	14.5310	2.80834	5.174	2.086349E-06
1/Max	0.438247	0.106496	0.0281	0.00633	4.115	1.041422E-04
1/Min	-0.432207	0.108163	-0.0218	0.00547	-3.996	1.573313E-04
1/FRZD1	0.186323	0.047327	5.8908	1.49630	3.937	1.924973E-04
Log(Max)	0.071356	0.018739	0.1189	0.03122	3.808	2.978181E-04



Viscosity

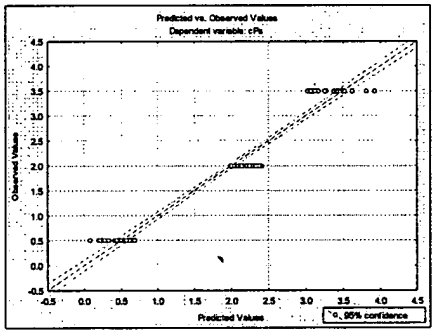
Regression Summary for Dependent Variable: cPs (Synthetic Impedance Data.sta)
R= .97696409 R²= .95445882 Adjusted R²= .95206192
F(4,76)=398.20 p<0.0000 Std.Error of estimate: .26970

	Beta	Std.Err.	B	Std.Err.	t(76)	p-level
Intercept			-15.694	0.9671	-16.2279	2.089853E-26
1/MinD2	-0.840896	0.035160	0.000	0.0000	-23.9160	4.151239E-37
FreqRMaxD1	0.506923	0.028371	5.662	0.3189	17.8679	6.229948E-29
MinD2	0.376456	0.033230	8268.383	729.8467	11.3289	5.432749E-18
Sqr_Min	-0.117944	0.024612	-10.112	2.1102	-4.7922	7.999455E-06



Regression Summary for Dependent Variable: cPs (Synthetic Impedance Data.sta)
R= .97873578 R²= .95792372 Adjusted R²= .95511883
F(5,75)=341.50 p<0.0000 Std.Error of estimate: .26096

	Beta	Std.Err.	B	Std.Err.	t(75)	p-level
Intercept			-17.653	1.214	-14.5445	1.57E-23
FreqLZeroD1	0.483355	0.029189	5.411	0.327	16.5596	9.17E-27
1/MinD2	-0.693825	0.058609	0.000	0.000	-11.8381	7.78E-19
Cub_Min	-0.189018	0.031429	-69.316	12.890	-5.3776	8.24E-07
MinD2	0.245608	0.065284	5394.464	1433.871	3.7622	3.32E-04
log(MaxD2)	-0.268470	0.097688	-0.284	0.103	-2.7482	7.50E-03



Regression Summary for Dependent Variable: cPs (Synthetic Impedance Data.sta)
R= .98468409 R²= .96960278 Adjusted R²= .96757827
F(5,75)=478.47 p<0.0000 Std.Error of estimate: .22181

	Beta	Std.Err.	B	Std.Err.	t(75)	p-level
Intercept			-12.938	0.8918	-14.5075	1.813827E-23
1/MinD2	-0.691178	0.043747	0.000	0.0000	-15.7994	1.434065E-25
PK	0.368418	0.029871	250.435	20.3047	12.3338	1.005152E-19
log(MaxD2)	-0.368199	0.043809	-0.390	0.0462	-8.4431	1.709891E-12
Cub_Min	-0.131400	0.023774	-53.869	9.7499	-5.5272	4.512695E-07
P27_D2	0.128036	0.028700	3078.767	690.1188	4.4612	2.817552E-05

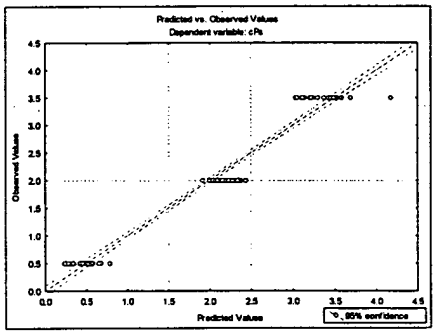
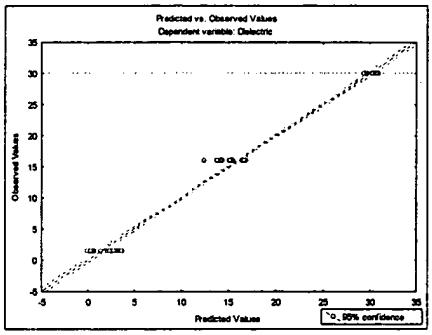


Fig. 8

Dielectric Constant

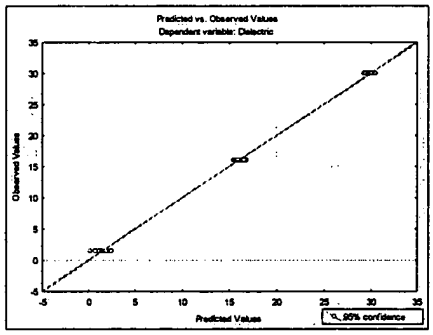
Regression Summary for Dependent Variable: Dielectric (Synthetic Impedance Data.sta)
R= .99511668 R²= .99025720 Adjusted R²= .98974442
F(4,76)=1931.2 p<0.0000 Std.Error of estimate: 1.1857

	Beta	Std.Err.	B	Std.Err.	t(76)	p-level
Intercept			-9.15	0.581	-15.7513	1.206053E-25
AvgD1	1.37132	0.054288	75492.69	2988.616	25.2691	1.029444E-38
Sqr_Max	-1.46807	0.108461	-1157.11	85.604	-13.5170	6.567799E-22
Cub_Avg	4.64294	0.880918	17514.38	2568.600	6.8187	1.924593E-09
Cub_Max	-2.46760	0.623828	-8978.25	2269.034	-3.9569	1.693159E-04



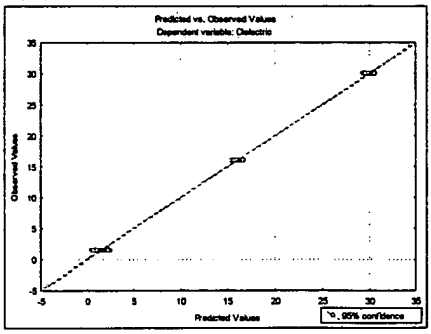
Regression Summary for Dependent Variable: Dielectric (Synthetic Impedance Data.sta)
R= .99943711 R²= .99887453 Adjusted R²= .99878328
F(6,74)=10946. p<0.0000 Std.Error of estimate: .40840

	Beta	Std.Err.	B	Std.Err.	t(74)	p-level
Intercept			-7.53	1.2377	-6.0807	4.808670E-08
AvgD1	0.66843	0.016800	36887.94	924.8812	39.6877	0.000000E+00
1/AvgD1	-0.197847	0.007860	-0.000163	0.000006	-25.1721	0.000000
Cub_Avg	2.44530	0.154098	9224.32	581.2968	15.8685	1.592333E-25
Sqr_Min	-3.33853	0.285158	-2720.66	232.3839	-11.7076	1.838648E-18
Min	1.54184	0.134232	304.33	26.4945	11.4884	4.100279E-18
Log(FMx_D1)	-0.01485	0.003953	-9.21	2.4530	-3.7556	3.421387E-04



Regression Summary for Dependent Variable: Dielectric (Synthetic Impedance Data.sta)
R= .99901744 R²= .99803585 Adjusted R²= .99795932
F(3,77)=13042. p<0.0000 Std.Error of estimate: .52890

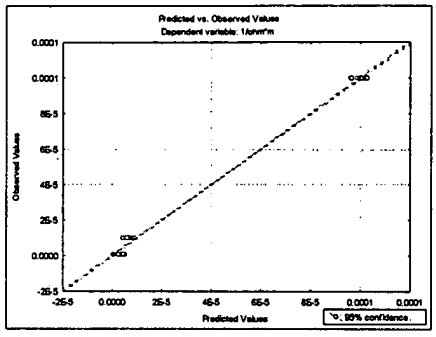
	Beta	Std.Err.	B	Std.Err.	t(77)	p-level
Intercept			35.64	1.2392	28.7567	6.24E-43
Cub_Min	0.676927	0.005494	2638.71	21.4159	123.2124	0.00E+00
AvgD1	0.656755	0.010915	36155.19	600.9014	60.1683	0.00E+00
Log(AvgD1)	0.401660	0.011145	10.63	0.2950	36.0399	0.00E+00



Conductivity

Regression Summary for Dependent Variable: 1/ohm*m (Synthetic Impedance Data.sta)
R= .99825839 R²= .99651982 Adjusted R²= .99633665
F(4,76)=5440.5 p<0.0000 Std.Error of estimate: .00000

	Beta	Std.Err.	B	Std.Err.	t(76)	p-level
Intercept			0.000112	0.000025	4.3989	3.495104E-05
Max	-3.84681	0.091876	-0.002934	0.000070	-41.9589	0.000000E+00
Min	3.86666	0.161681	0.002932	0.000123	23.9154	4.158121E-37
Cub_Min	0.47895	0.064796	0.007172	0.000970	7.3916	1.594179E-10
Log(Min)	0.37400	0.089082	0.000063	0.000015	4.1993	7.204409E-05



Some Definitions of Variables

Min	Minimum Impedance in Spectrum
Max	Maximum Impedance in Spectrum
Avg	Average Impedance in Spectrum
PK	Frequency of 1st Derivative Minimum Value (an inverted PeaK)
Sqr_	Square_of_
Cub_	Cube_of_
Log()	Log10 of
1/	Reciprocal of
D1	First Derivative of Impedance vs Frequency
D2	Second Derivative of Impedance vs Frequency
D3	Third Derivative of Impedance vs Frequency
MinD1=	Minimum of First Derivative of Impedance in Spectrum
MaxD1=	Maximum of First Derivative of Impedance in Spectrum
MinD2=	Minimum of Second Derivative of Impedance in Spectrum
MaxD2=	Maximum of Second Derivative of Impedance in Spectrum
1/FMn_D1	Reciprocal of Frequency of Minimum D1 (Inverted Peak)
1/FMx_D1	Reciprocal of Frequency of Maximum D1
FreqAtMinD1	Frequency of Minimum D1 (Inverted Peak)
FreqAtMaxD1	Frequency of Maximum D1 (May pick small bump on either side of Inverted Peak)
FreqAtMinD2	Frequency of Minimum D2
FreqAtMaxD2	Frequency of Maximum D2
FreqAtMinD3	Frequency of Minimum D3
FreqAtMaxD3	Frequency of Maximum D3
FreqLMaxD1=	Frequency of LEFT Maximum D1 (Left of Inverted Peak)
FreqRMaxD1=	Frequency of RIGHT Maximum D1 (Right of Inverted Peak)
FreqLZeroD1=	FLZD1 = Frequency of LEFT Zero D1 (Left X-axis Crossing Point)
FreqRZeroD1=	FRZD1 = Frequency of RIGHT Zero D1 (Right X-axis Crossing Point)

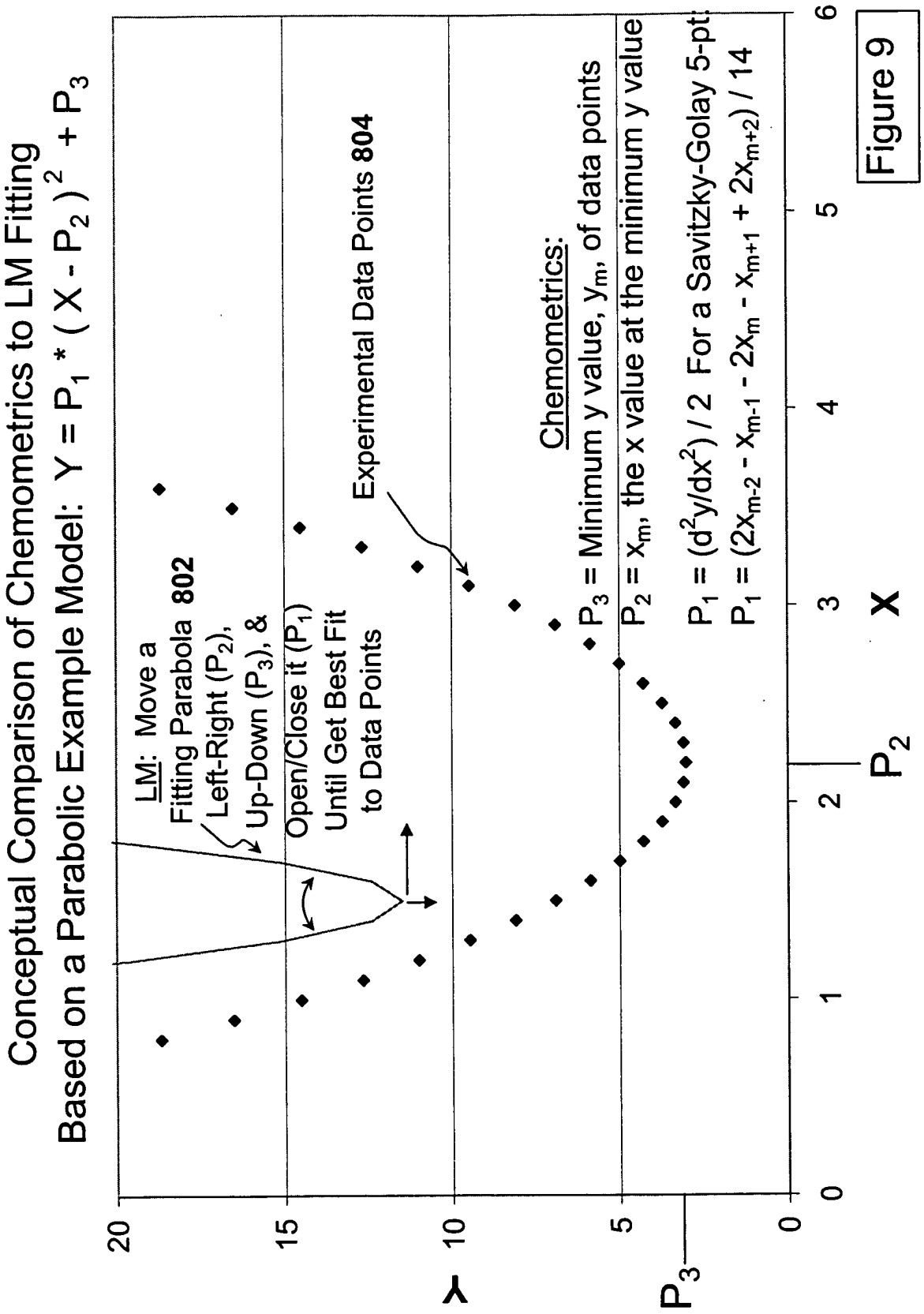

Conceptual Comparison of Chemometrics to LM Fitting
Based on a Parabolic Example Model: $Y = P_1 * (X - P_2)^2 + P_3$
LM: Move a Fitting Parabola 802
Left-Right (P_2),
Up-Down (P_3), &
Open/Close it (P_1)
Until Get Best Fit
to Data Points
Experimental Data Points 804
Chemometrics:
P_3 = Minimum y value, y_m, of data points
$P_2 = x_m$, the x value at the minimum y value
$P_1 = (d^2y/dx^2) / 2$ For a Savitzky-Golay 5-pt:
$P_1 = (2x_{m-2} - x_{m-1} - 2x_m - x_{m+1} + 2x_{m+2}) / 14$
Y
X
P_3
P_2
0
5
10
15
20
0
1
2
3
4
5
6

Figure 9

Dominant Response Features of a Tuning Fork Immersed in Different Fluids

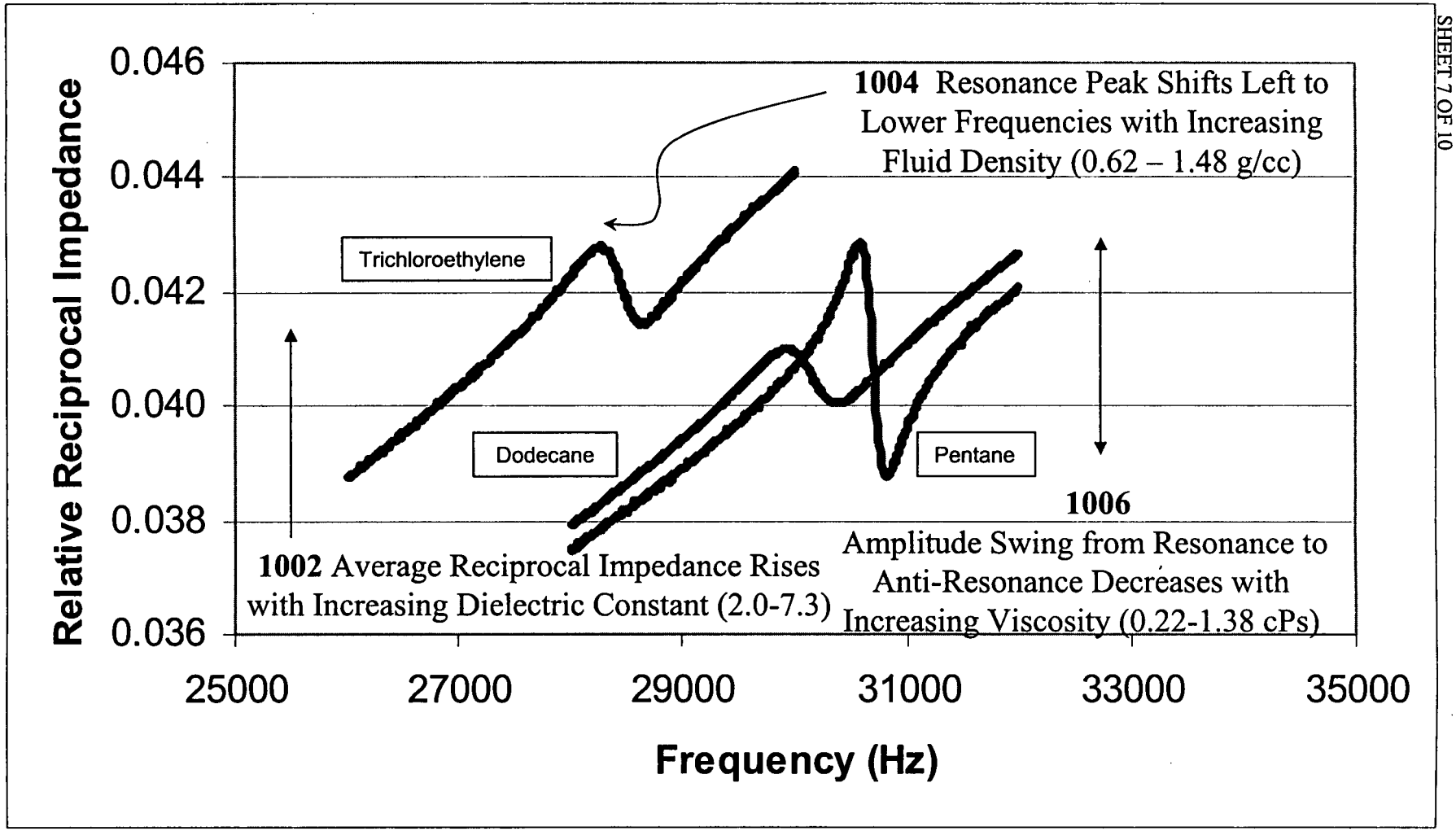


Figure 10

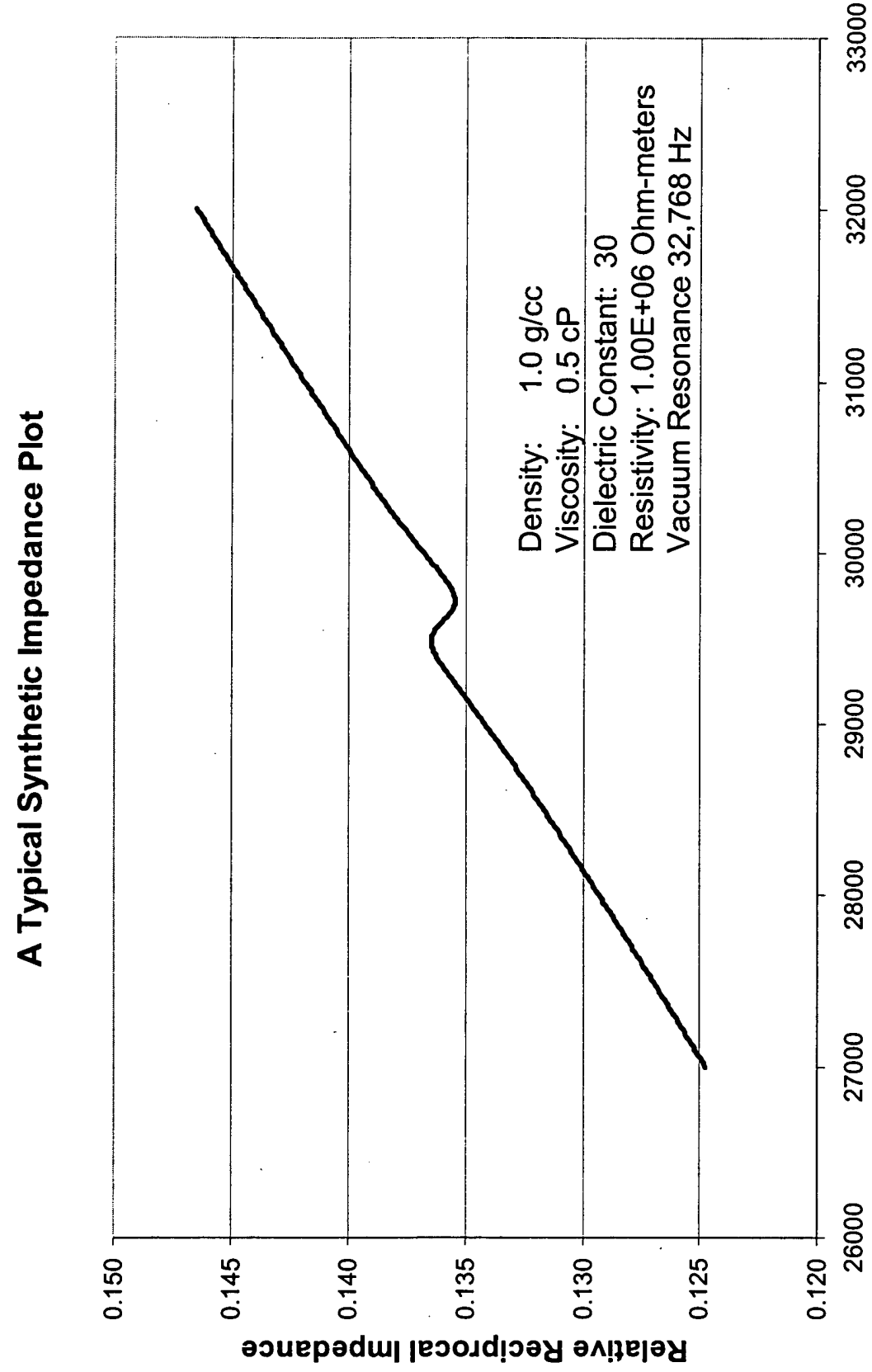

A Typical Synthetic Impedance Plot
Relative Reciprocal Impedance
0.150
0.145
0.140
0.135
0.130
0.125
0.120
Frequency
26000
27000
28000
29000
30000
31000
32000
33000
Density: 1.0 g/cc
Viscosity: 0.5 cP
Dielectric Constant: 30
Resistivity: 1.00E+06 Ohm-meters
Vacuum Resonance 32,768 Hz

Figure 11

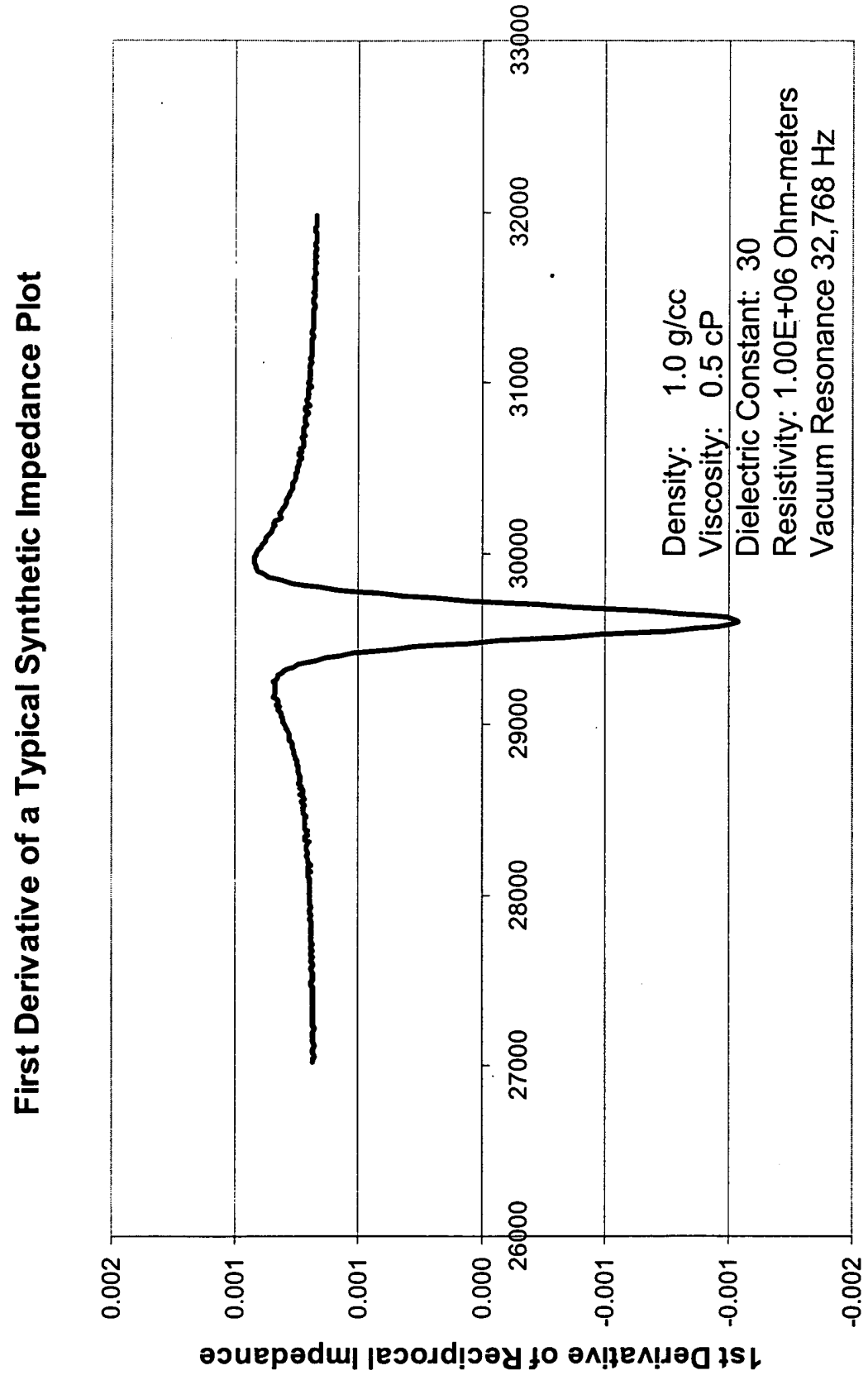

First Derivative of a Typical Synthetic Impedance Plot
1st Derivative of Reciprocal Impedance
0.002
0.001
0.001
0.000
-0.001
-0.001
-0.002
26000
27000
28000
29000
30000
31000
32000
33000
Frequency
Density: 1.0 g/cc
Viscosity: 0.5 cP
Dielectric Constant: 30
Resistivity: 1.00E+06 Ohm-meters
Vacuum Resonance 32,768 Hz

Figure 12

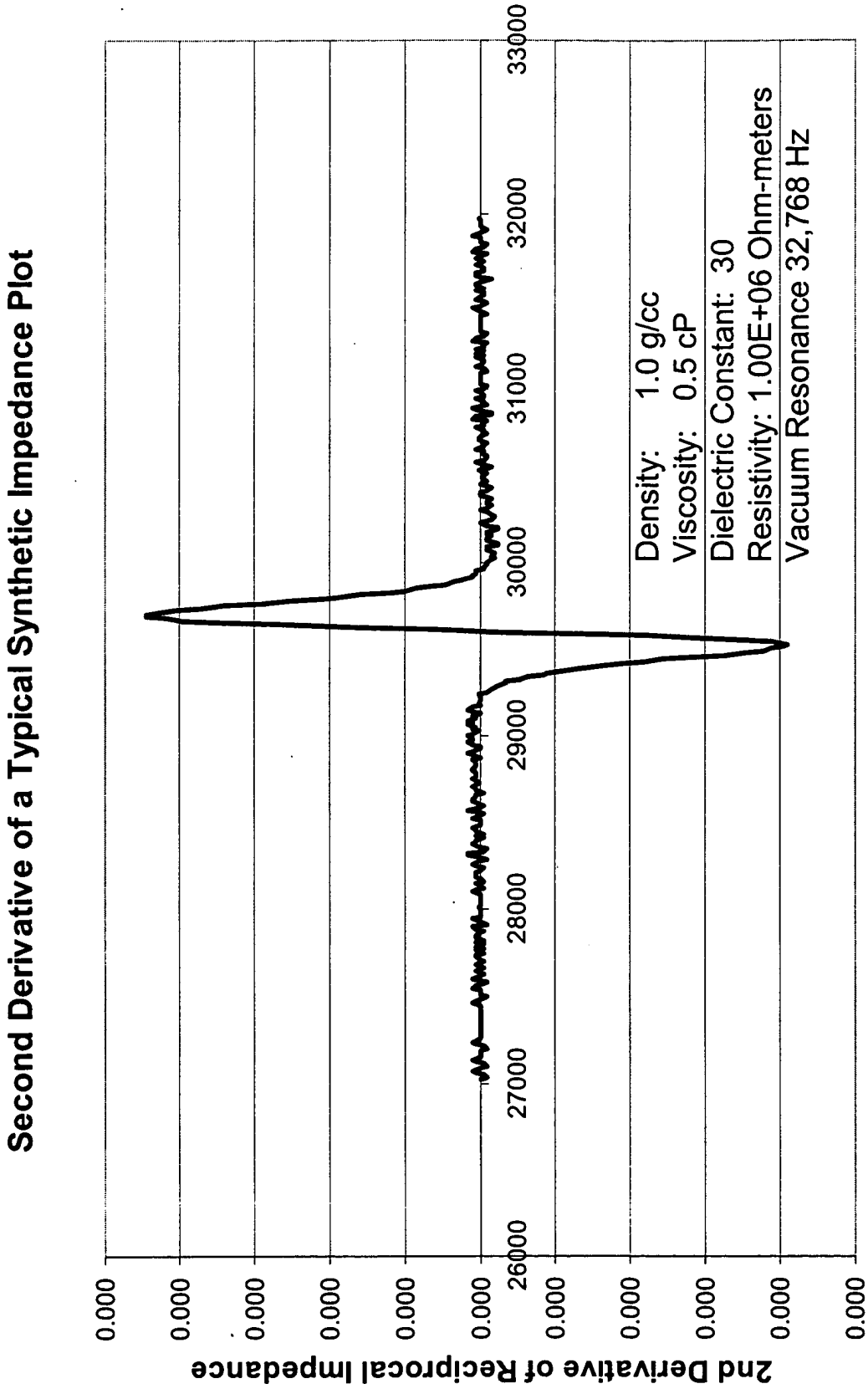

Second Derivative of a Typical Synthetic Impedance Plot
2nd Derivative of Reciprocal Impedance
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
26000
27000
28000
29000
30000
31000
32000
33000
Frequency
Density: 1.0 g/cc
Viscosity: 0.5 cP
Dielectric Constant: 30
Resistivity: 1.00E+06 Ohm-meters
Vacuum Resonance 32,768 Hz

Figure 13